THE REGIMES AND CYCLICAL VOLUME CHANGES OF THE UPPER MURRAY AND SNOWY RIVERS, NEW SOUTH WALES.

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(Twelve Text-figures.)

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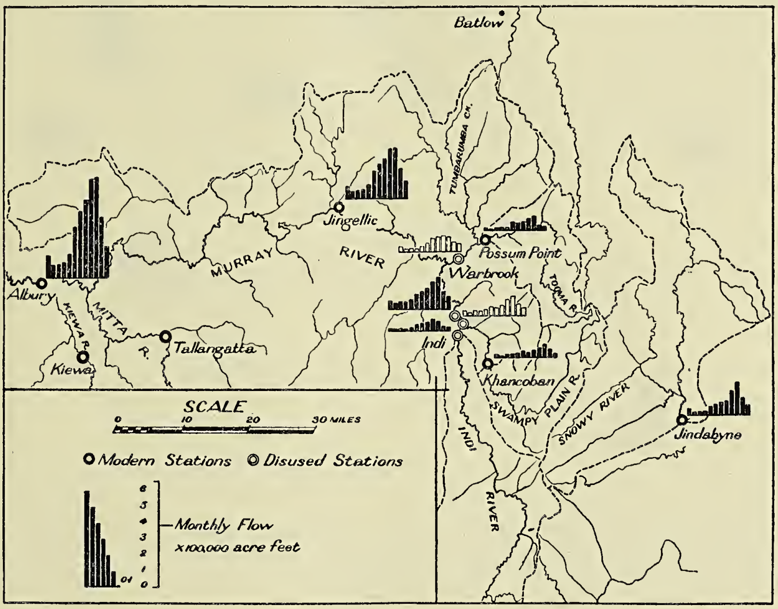
Introduction.

The study of modern erosional forms in the Hume catchment of New South Wales discloses a progressive action in the formation of gullies and terraces, and a gradual widening of the main stream channels away from curves, even in places where the banks are protected by grass, shrubs and lines of trees. These facts suggest many possibilities in the way of changing stream regime or secular alterations in volume, and it may be asked: Is the duration or intensity of the annual flood changing? Is the winter flow benefiting at the expense of the summer flow? Is there any secular change in the volume discharged, and, if so, can it be referred to such causes as deforestation or changes in the rainfall regime? The answers that can be given to these questions depend mainly on the records of stream gaugings kept by State authorities, with definite limitations imposed by short records at certain stations, and by the absence of rainfall data for the wettest part of the catchments. Thus it is impossible to consider the lag between precipitation and stream rise, but the questions suggested above can be answered with some precision, as the records available are consistent for the periods which they cover. For this reason, the secular trends disclosed below are of similar gradient when computed for partial or complete records, and when the figures for the various Murray stations are plotted against one another, they show a linear relationship (Text-figs. 8, 9). In addition, the form of the curves on which the present conclusions are based, especially in the duration and distribution of notably moist or drought periods, leaves no doubt of the general correctness of the various trends.

Regime of the Upper Murray and Snowy Rivers.

The characteristic regime shows a maximum flow in September or October and a minimum in February (Text-fig. 1). It is thus simple, and equivalent to the European regime nival de plaine.* Streams with a large proportion of catchment liable to snow in quantity (Tooma, Swampy Plain and Snowy), have a slight concavity in the graph before the wave crest, but others less influenced by snow



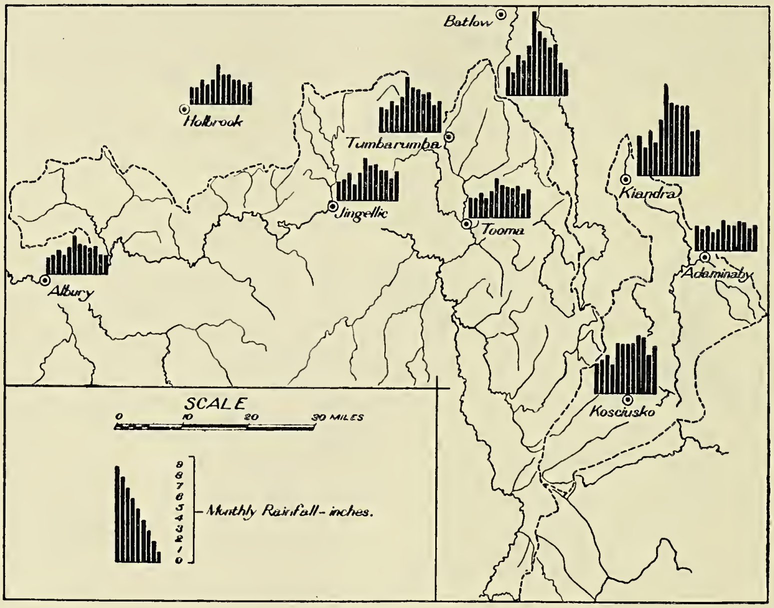
Text-fig. 1.—Stream regimes of the upper Murray and Snowy Rivers, from January on the left to December on the right. Periods of record are: Albury, 1877-1932; Jingellic, 1891-1932; Tallangatta, 1886-1932; Warbrook, 1910-1920; Indi, 1908-1920; Murray at Indi-Swampy Plain junction, 1906-1920; Swampy Plain at Indi junction, 1906-1913; Khancoban, 1927-1932; Possum Point, 1927-1932; Jindabyne, 1903-1932. Hollow columns are used to distinguish records of secondary importance in the making of the complete regime at Albury or Jingellic.

display convexity instead (Indi, Murray). The relationship between the two forms is shown in the case of Tooma River, where the modern gauge at Possum Point gives records with pre-maximum concavity, thus contrasting with the older records at Warbrook, below the junction of Tumbarumba Creek. In addition to these major features, there are minor oscillations in the late summer records of the Indi, Tooma and Swampy Plain, but they are too small to have any significance ascribed to them over so short a period.

Comparing stream and rainfall regimes (Text-fig. 2), a general similarity is seen in the minimal periods, but the rainfall maximum occurs three to four months

* See Pardé, 1933.

before the stream floods. The position is rather obscure, as the significance of the 20-year Kosciusko record is not known. If the high plateau at the head of the Tooma, Swampy Plain and Snowy Rivers has a rainfall regime like that indicated for Kosciusko, the importance now attached to conserved snow in the economy of the streams will be lessened, but it must be noted that the estimation of winter

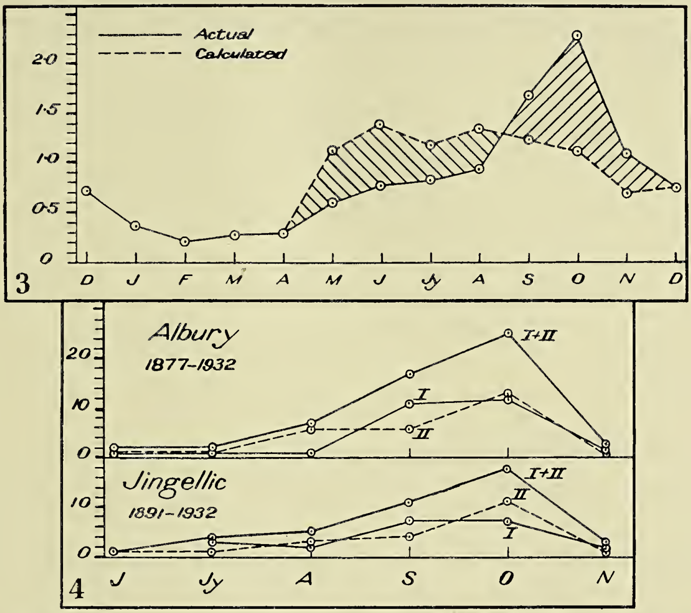


Text-fig. 2.—Rainfall regimes, from January on the left to December on the right. Periods of record are: Albury, 1877; Kiandra, 1883; Holbrook and Tooma, 1885; Tumbarumba, 1886; Adaminaby and Batlow, 1887; Jingellic, 1909; Kosciusko, 1912, extending to 1932 in each case.

precipitation at Kosciusko is likely to be inaccurate, because individual estimates of water content are not made for each sample of snow in the gauge. The best summary that can be given at present is, that a rainfall maximum is shown in June for most of the area, and that precipitation is sustained until the beginning of the warm season in October. In this way, much of the effective rain for stream flow comes in late winter or early spring both in highland and lowland areas, or the Albury river graph would show a crest before the incidence of the annual flood from the highlands in September and October. In the higher country, delay of the flood peak is caused by the accumulation of water in the form of snow (Text-fig. 3), and in the lower it is due to the necessity of making up a moisture deficiency in the ground after the warmer months. Thus highland and lowland are mutually supporting in the development of the flood wave.

The time of occurrence of the flood crest, which is a peak rather than a flat wave of any great dispersion, is controlled by such factors as flood rains on various parts of the catchment, or heavy rain falling on melting snow. Of the recorded occurrences, 43% to 45% are found in October, and the moieties of the gauging records at Jingellic and Albury give a similar time distribution (Text-fig. 4).

So far as the dry period is concerned, the most striking aspect is the close relationship between the stream and rainfall curves, even though the temperature factor cannot be taken into account because the only two recording stations



Text-fig. 3.—Effect of snow conservation on the flow of the Snowy River, Jindabyne, for the period 1912-1932. The average precipitation at the stations Adaminaby, Kiandra and Kosciusko for the months May-November was taken as the rainfall over the catchment, and the difference between run-off calculated on this basis and that actually measured at Jindabyne was reckoned as evaporation (28% of the possible). This was distributed according to a formula:

$$\text{Evap. for month} = \text{Total Evap.} \times \frac{\text{Relative Evap. for month}}{\text{Sum of Relative Evapns.}},$$

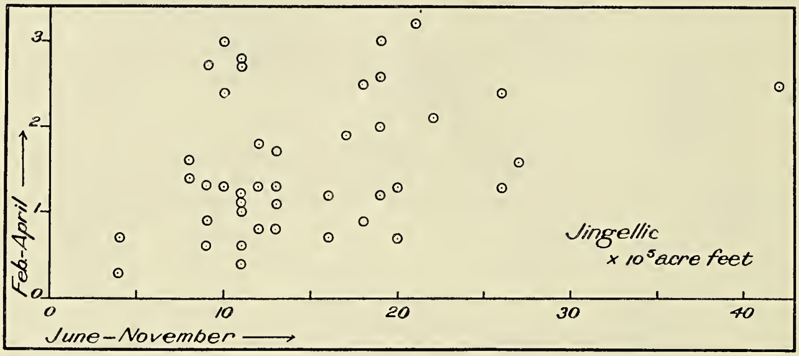
where the relative evaporation was taken as Precipitation × (T + 10), with the temperature (T° C.) as the average monthly temperatures at Kiandra and Kosciusko. This is an adaptation of de Martonne's climatological ratio for the effectiveness of precipitation (1927). The rulings show conservation (May-August) and dissipation of snow (September-November).

Text-fig. 4.—Frequencies of flood crests by months, Albury and Jingellic. The first half of each record is represented by I, and second by II, and the total by I + II.

(Kiandra and Kosciusko) are not representative. Stream flow in the dry period depends mainly on proximal rainfall, and only to a minor degree on the carry-over of water stored in the catchment as the result of winter rain and snow. This becomes clear when the rain and flow records are studied month by month, and it is demonstrated by the lack of any close correlation between the run-off in winter and that in the low-water months of the following summer (Text-fig. 5). Thus a moist winter is not necessarily an indicator of high volumes in the following summer, and a relatively large summer flow may follow a dry winter. *In other words, summer or low-water flow cannot be treated as a function of winter flow.*

Cyclical and Secular Changes in Volume.

a. Cyclical Changes.—Having described the normal seasonal fluctuations of volume, it may now be asked: have the volumes discharged annually, or during flood and low-water seasons, varied from time to time according to some general cyclical or secular law? It has long been remarked that years of exceptional drought or flood occur in Australia with a suggestion of an 11-year periodicity.

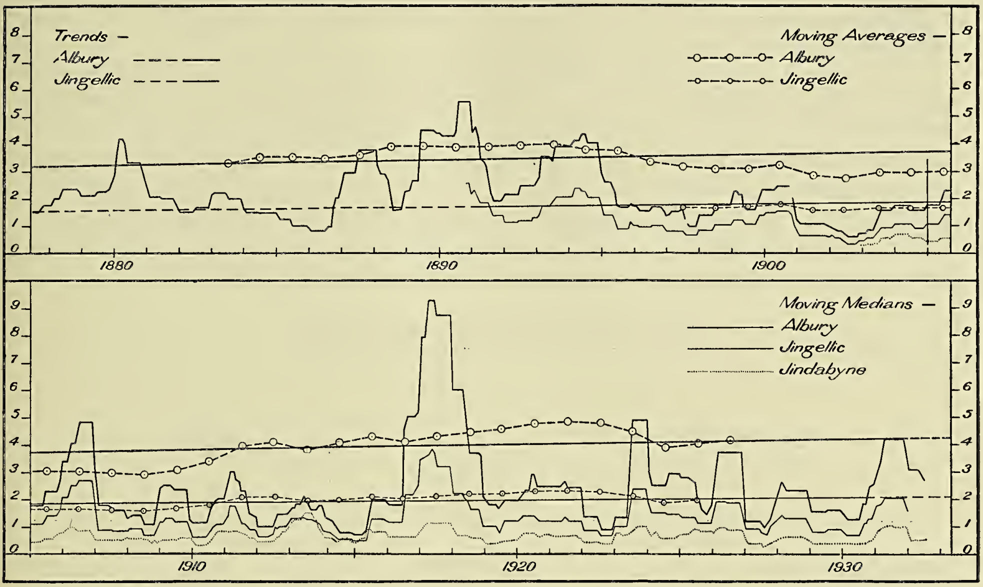


Text-fig. 5.—Low water at Jingellic plotted against the flood volume of the preceding winter for the years 1891-1932. There is no apparent relationship.

This is the case with the upper Murray, where years of outstandingly low flows were 1884, 1902, 1914 and, to a lesser extent, 1929: years of exceptional flood were 1887, 1889, 1894, 1906, 1917 and 1931. The fact has little meaning in itself, as an exceptional flood or drought may be only a local peak or trough in a series of consistently high or low values; it is necessary, for this reason, to combine the various records in series to find whether there is any true periodicity, and to see if a secular trend may be deduced.

In making such a combination, the crude annual totals are disregarded, because each represents only one out of every twelve possible combinations of twelve consecutive months, and this makes a number of anomalies possible. For instance, it is not uncommon to find a high value for one month in a consistently low series of 16 or 18 months, but the position of this high value within the normal flood limits makes an annual total possible which disguises the actual paucity of flow over a lengthy period. To overcome such difficulties, every possible combination of 12 consecutive months has been taken, the monthly gaugings arranged in order of magnitude, and the value between the sixth and seventh chosen as the median, to be attributed to the seventh month of the series. Thus with a series commencing in July, the median is credited to the following January, that of the next to February, and so on. In this way, a set of values is obtained to give a regular index of flow in the river (Text-fig. 6 shows these "moving medians").

Another method would be to use the arithmetical mean in a similar manner, but the median has several advantages in practice, of which the principal are: (1) A smoother curve is obtained in plotting, as the chance of two consecutive means being equal is small, while the median may not vary over 11 or 12 months; (2) Excessive weight is not given to one or two exceptionally large or small values in a series. In a test, it was found that the moving median gave values to 30% below the moving mean in periods of greatest flow, and values to 20% above the moving mean in periods of excessive drought. The median curve is thus distinctively conservative; (3) For three stations—Jindabyne, Albury and



Text-fig. 6.—Fluctuations of the upper Murray and Snowy Rivers. The moving median with a 12-month period, plotted monthly, eliminates the annual wave: the 13-year moving average of annual totals eliminates the minor cycles, and the computed trend gives the secular movement of volume. For the medians, ordinate numbers are multiplied by 100,000 acre-feet: for the averages and trends, by 1,000,000 acre-feet. Scales are thus in the ratio—median : average = 12 : 10.

Jingellic, of which the first is on the upper Snowy, and the last Victorian—the curves obtained show synchronous changes of slope for all major and almost all minor variations. In this respect, the moving median is unexpectedly sensitive. The greatest anomaly is with respect to the 1931 flood on the Murray, which appeared much too low in comparison with earlier peaks, especially that of 1917. In these two cases, the Murray at Albury discharged 9 million acre-feet between June and November, 1917, and 6½ million acre-feet during a similar period in 1931: the excessive median difference was the result of high values in 1916 and 1918 compared with relatively low values during 1930 and 1932. Apart from this, however, the method appears to have given a true picture of flow conditions.

Referring to the graphs, it is found that there has been a regular cyclical variation in flow, with major crests for Albury in 1880, 1891, 1906, 1917 and 1931, and notable troughs in 1877, 1886, 1902, 1914 and 1922, giving an average interval of 13 years for the crests, and of 12 years for the troughs. In addition, the mid portion of the graph between 1894 and 1917 is consistently low, but is succeeded by greater volumes to the present day. For this reason, too much attention should not be paid to the minor cycles noted, but the record may be looked on as showing an early trough, a crest centred about 1890, a middle trough, and a later humid period which may exist until now. This is brought out by a curve showing a 13-year moving average of annual totals, whose period was chosen to eliminate the minor cycles as far as possible.

There are minor cycles in the flow of the Murray with a 12- or 13-year period, but they are overshadowed by a major cycle which may have a period of the order of 30 years.

b. Secular Changes.—The median graphs and 13-year moving average curves show a rising tendency in the flow of the Murray, reflected in the increased volume and dispersion of major floods, but the reverse is true of the shorter record for the upper Snowy. That record includes the excessive flood of 1917, but has no equivalent of the 1931 floods on the Murray, so a calculated trend may be expected to show a slight decline. The general trends were approximated to straight lines by the calculation of least squares, both for unweighted annual flows and for 13-year moving averages, with these results (Table 1).

TABLE 1.—*Annual Trends for Various Stations.*

Station and Period.	Thousands Acre-Feet.		% Annual Increase.	% Total Increase.
	Ordinate at Beginning.	Ordinate at End.		
Albury, 1878–1932	3,190	4,210	0·5	32
Albury, 1891–1931	3,090	4,370	0·9	41 (*a*)
Jingellic, 1891–1931	1,709	2,057	0·5	20
Jingellic, 1904–1932	1,878	2,088	0·4	11
Jindabyne, 1904–1932	985	887	−0·4	−10
Moving Averages.				
Albury, 1878–1932	3,130	4,250	0·6	36
Jingellic, 1891–1931	1,400	2,320	1·3	66 (*b*)

(*a*) Probably high, as the flows immediately preceding were high. (*b*) Unduly weighted by low initial averages.

The gain on the Murray side is definite and persistent, whether determined for longer or shorter periods, and it is not yet certain that this gain has ended. However, the secular trend of the Murray has favoured increased flow over the period of record, but the Snowy appears to be losing at much the same rate as the upper Murray is gaining. The distribution of these changes within the year assigns their greater portion to the flood or winter season (Table 2), but the low water trends, although smaller in magnitude, are also positive for the Murray and negative for the Snowy (Table 3).

From this it is clear that the various fluctuations of volume of the two rivers have varied regularly over the periods recorded. The tendency for the Murray has been towards a more intense flow over the six cooler months, and the cyclical fluctuations have shown a rising trend. The reverse is true of the upper Snowy.

CAUSE OF THE CHANGES.

Having defined the nature and amount of change in the flow of the rivers, it remains to be seen whether the changes can be ascribed to any major cause

TABLE 2.—*Flood Volume Trends—(June–November).*

Station and Period.	Thousands Acre-Feet.		% Annual Increase.	% Total Increase.
	Ordinate at Beginning.	Ordinate at End.		
Albury, 1878–1932	2,440	3,400	0·6	39
Albury, 1891–1931	2,410	3,530	0·9	46
Jingellic, 1891–1931	1,326	1,614	0·5	22
Jindabyne, 1904–1932	732	698	−0·1	−4·6

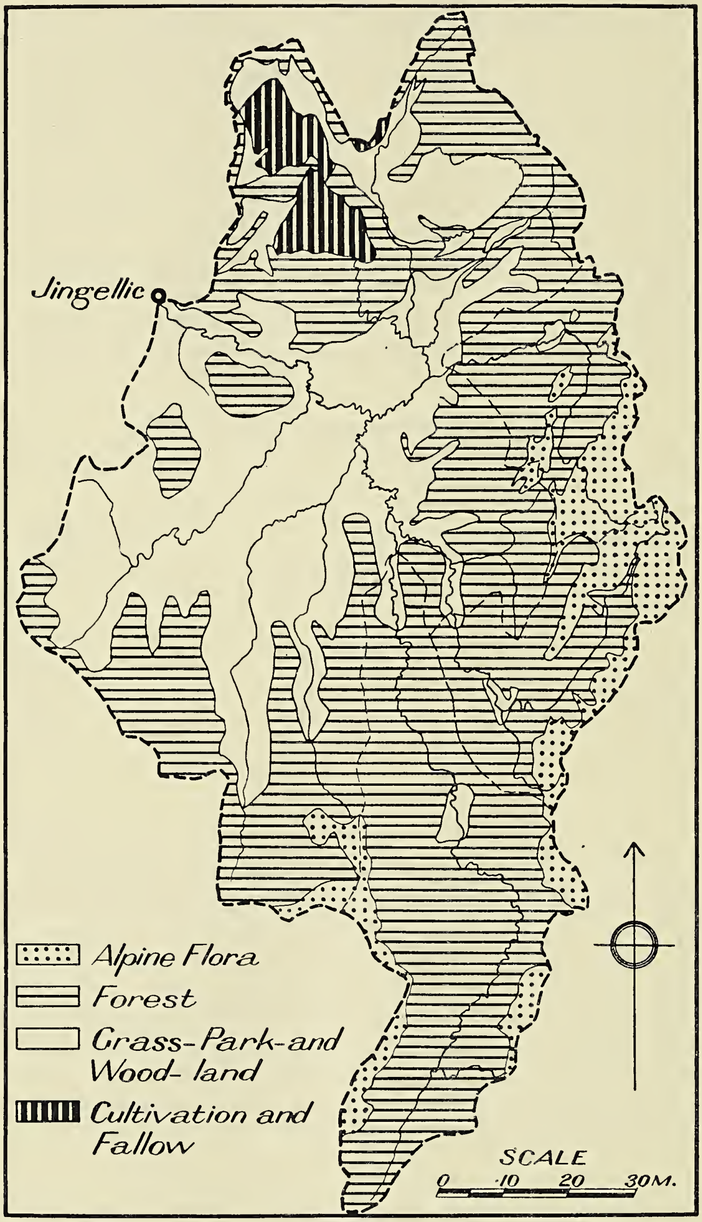
TABLE 3.—*Low Water Trends—(February–April).*

Station and Period.	Thousands Acre-Feet.		% Annual Increase.	% Total Increase.
	Ordinate at Beginning.	Ordinate at End.		
Albury, 1878–1932	291	297	0·05	2
Jingellic, 1891–1931	150	156	0·1	4
Jingellic, 1904–1932	117	189	1·6	61
Jindabyne, 1904–1932	81	76	−0·2	−6

or causes. Opposite effects in the upper Snowy and Murray suggest that the windward slopes to the west have been gaining at the expense of the leeward eastern slopes towards Jindabyne, and on a first inspection the cyclical nature of the median curves seems to point to climatic change of some kind. In the past, the possible effect of deforestation has been greatly stressed: thus Wood (1923, 1928) urged the destruction of forests as the prime cause of a supposed decrease in the summer flow of the Murray, and the increased intensity of winter floods. Despite this, deforestation would appear to be a much less potent factor than redistribution of rain within the year, and the apparent changes of rainfall are enough to give changes of river trend of the order of magnitude involved. The two aspects will be considered in turn.

a. The Factor of Deforestation (Text-fig. 7).

As the various parts of the catchment are of unequal value for the output of water, the removal of equal areas of forest from the highlands, hill country and valleys will not be expected to have the same effect on water supply. The mountain streams Indi, Swampy Plain and Tooma drain only 36% of the Jingellic catchment, but they give 69% of the annual and 76% of the summer volumes (Table 4).



Text-fig. 7.—General utilization of the Murray catchment above Jingellic. The area of partially deforested grassland, etc., to the south-west of the Murray is probably exaggerated. Boundaries of Alpine flora are largely after unpublished reports and maps by B. U. Byles (1932*b*).

TABLE 4.—*Output of Water, and Relative Efficiencies of the Various Portions of the Jingellic Catchment for the Years 1927 to 1932, inclusive.*

Relative Efficiencies of the Catchment Areas.

Stream.	Area of Catch-ment.	% of Total.	Volume, 1927-1932.	% of Total.	Summer Volume.	% of Total.
Tooma River	189	7·5	2,666	24	414	20·6
Swampy Plain River	228	9·0	2,651	24	578	28·8
Indi River	493	19·5	(2,320)[1]	21	(537)	26·8
Balance of Country	1,614	64·0	3,367	31	474	23·7
Murray River at Jingellic	2,524	100·0	11,004	100	2,003	100·0
Snowy River at Jindabyne	716	—	4,945	—	855	—

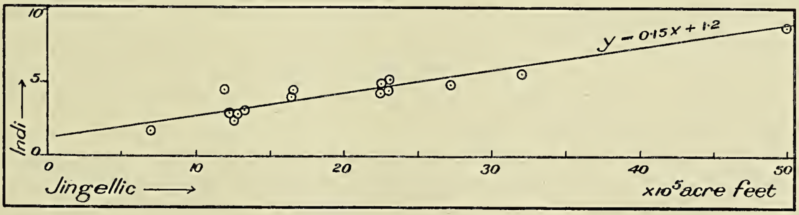
[1] From relationship in Text-Figure 8.
N.B.—*Summer* is taken as *December to April inclusive*, i.e., 5 months.

Efficiencies Relative to Balance of Country outside Mountain Catchments.

	Annual.	Summer.	S/A.
Tooma River	7·0	7·4	1·1
Swampy Plain River	5·8	8·6	1·5
Indi River	2·4	3·7	1·5
Balance of Country	1·0	1·0	1·0
Murray River at Jingellic	2·2	2·7	1·2
Snowy River at Jindabyne	3·4	4·0	1·2
Swampy Plain + Tooma	6·3	8·4	1·3

The Indi is interpolated on the basis of its linear relationship with Jingellic during the years 1906 to 1920 (Text-fig. 8).

On the other hand, the balance of the country, which gives 31% of the annual and 24% of the summer discharge, has suffered the greatest amount of deforestation, and, near the Murray, parts of even the steeper hills and ridges have been cleared for grazing (Table 5, Text-fig. 7).



Text-fig. 8.—Annual flows of Indi and Jingellic stations for the period 1906-1920. Records are from New South Wales and Victorian sources respectively.

TABLE 5.—*Utilization of the Murray Catchment above Jingellic.*

Utilization of the Upper Murray Catchment.

Locality.	Alpine.	Forest.	Grass and Parkland.	Grass and Cropland.	Area.
A.—By Area (Square miles).					
Tooma River	59	124	6·5	—	189·5
Swampy Plain River	73·5	148	5	—	226·5
Indi River	53·5	420	19	—	492·5
New South Wales hills	7·5	398	314	67	786·5
Victorian hills	31	333	465	—	829
Total	224·5	1,423	809·5	67	2,524
					Deforested.
B.—By Percentage.					
1.—Tooma River	31	65·5	3·5	—	3·5
2.—Swampy Plain River	32·5	65·3	2·2	—	2·2
3.—Indi River	11	85	4	—	4
4.—New South Wales hills ..	1	50·5	40	8·5	48·5
5.—Victorian hills	4	40	56	—	56
Total	9	56·5	32	2·5	34·5
% Mountains, 1, 2, 3	20·5	76	3·5	—	3·5
% Hills, 4, 5	2·5	45	48	5	53

" Grass and Parkland " includes small areas of cultivation, and is likely to include some forested areas in the Victorian hills.

In assessing the amount of forest change and actual deforestation, the first question that arises is: Has the efficiency of the mountain catchments altered as the result of vegetational changes due to bushfires, apart from complete deforestation? It appears not, because, although the flora has degenerated over considerable areas and may be greatly damaged by any future combination of years of excessive drought and fire, it still forms a mantle over the whole countryside that is effective for present water supply purposes. The vegetational changes have been studied by B. U. Byles, lately of the Commonwealth Forestry Bureau, Canberra (1932*a*), and may be summarized according to the principal divisions into Alpine and forest lands, thus:

i. *Alpine.*—Part of the original cover of low shrubs has been replaced by tufted grasses such as snow grass (*Poa caespitosa*), and the original open stands of low Eucalyptus such as snow gum (*E. coriacea*), with trees 50 feet apart or more, have been largely destroyed and replaced by coppice, part of which has been subsequently burned. On the lower slopes of the division, just above the regular forest belt, the coppice and new intergrowth of shrubs form an almost impenetrable tangle. Parts of the highland swamp mosses have been damaged by fire, but they still conserve water.

ii. *Forest.*—On the high plateau, the forest areas south of Kosciusko and on the northerly Tooma slopes have not been greatly affected. The open forests about the heads of the Swampy Plain and Tooma Rivers have been destroyed on some ridges, and replaced by Alpine grasses or shrubs or by dense coppice: the essential change is from very open forest or park land to scrub country. In the case of the forests on the flanks of the high plateau, the old trees have been thinned out, or destroyed over small areas, of which the principal lies to the west of the upper Swampy Plain River. The former glades have been filled with bracken and low scrub, whose permanence is open to doubt, but there is no reason for supposing that the water supply has yet been affected by the changes which have decreased the vegetational cover in limited areas, and increased it in others. On the whole, the type of cover on the high plateau and its flanking slopes has not changed essentially: forest remains as forest, heath as heath, and swamp as swamp.

So far as the lower plateau and valley country in the balance of the area is concerned (N.S.W. and Victorian hills in Table 5), much of the cleared portion is lower slope or bottom land, while most of the hills and ridges do not appear to have departed greatly from their original condition. It seems that the deforested portion is that which would be expected to supply relatively little run-off in any case, so the effects of partial deforestation have probably been minimized by the location of clearings.

Summing up, it is found that changes in stream flow due to removal of tree cover must be ascribed principally to the 53% deforested or partially deforested country in the balance outside the mountains. Thus a volume which is probably less than half of the 31% contribution to the Jingellic flow comes from the deforested portion, so that changes due to deforestation involve a fraction of 15% of the Jingellic flow. It has already been shown that the total increases in annual and winter trends have amounted to 20% and 22% respectively between 1891 and 1931, or 17% and 18% respectively of the trend ordinate, so it is clear that the changes recorded are of a much greater order of magnitude than those expected from partial deforestation.

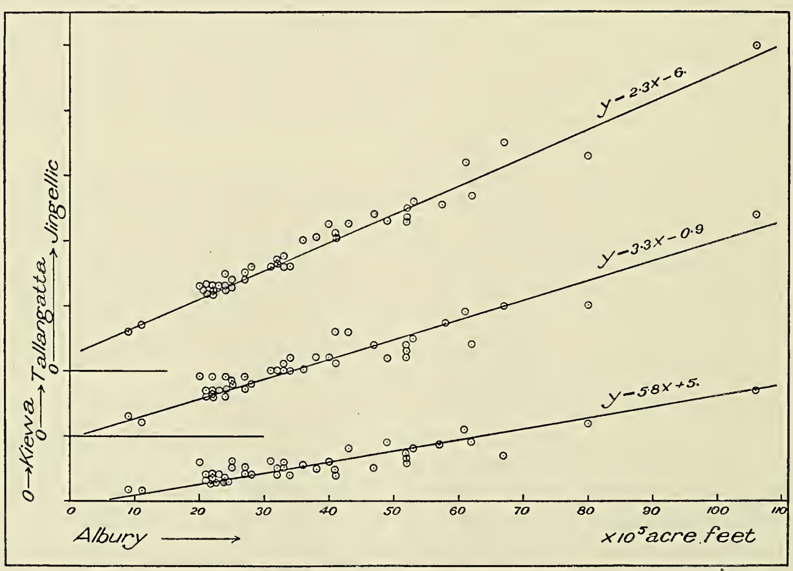
Before extending these considerations to the Albury catchment as a whole, it is necessary to consider anomalies in certain stream records. The combined figures for Jingellic, Tallangatta and Kiewa should disclose a trend like that of Albury, but actually they give only half the ordinate increase expected for the period 1891-1931—a fact reflected by trend increases of 1% and 6% for Tallangatta and Kiewa respectively. At the same time, Albury shows both positive and negative anomalies when its figures are compared with those of the contributing stations combined, with a regular distribution (Table 6).

It is difficult to see that a negative anomaly should result at all in practice, because the individual gauges are close to Albury, 80% of the annual flow is during the months June–November, and the upstream water is supplemented by perennial streams draining 1,700 square miles of additional catchment. From the distribution of the negative anomalies and their occurrence throughout the record, it appears that they are due to constant systematic errors in gauging, extending back to 1891, at any rate.

TABLE 6.—*Distribution of Anomalies between Albury Gaugings and the Combined Figures of Jingellic, Tallangatta and Kiewa.*

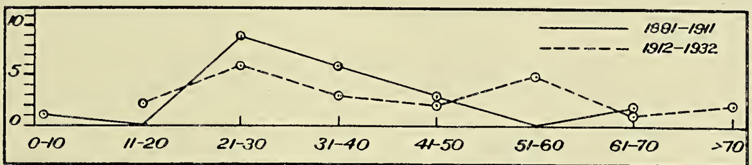
Flow at Albury— × 100,000 Acre-Feet.	Anomaly as Percentage of Albury Total.							
	Negative.				Positive.			
	<16	15–11	10–6	5–0	0–5	6–10	11–15	>16
0–10		/						
11–20	/			/	/			
21–30			////	///// ////		/		
31–40				//	//// ///			
41–50			/		/	///		
51–60						/		////
>60				/	/	/		//

What effect has this on the validity of the various trends? The contributing stations have an approximately linear relationship with Albury (Text-fig. 9),



Text-fig. 9.—Annual flows at Jingellic, Tallangatta and Kiewa plotted against Albury, with equal vertical and horizontal scales, but varying x-axes.

and are generally consistent amongst themselves, so it is possible that the lower range, especially at Albury, is too low, or that corresponding figures for the others are too high. If the former alternative is correct, the trend ascribed to Albury for the period 1891-1931 is excessive, but the others may be reasonable. If the second alternative is accepted, the Albury figures stand, and the trends for some or all of the contributing stations are increased. It is probable that some of the lower positive anomalies of Table 6 are also understated; this would affect the results in a manner similar to that in the second alternative owing to the greater frequency of high flows in the latter half of the period under discussion (Text-fig. 10), but there is no reason for doubting the general accuracy of the maxima.



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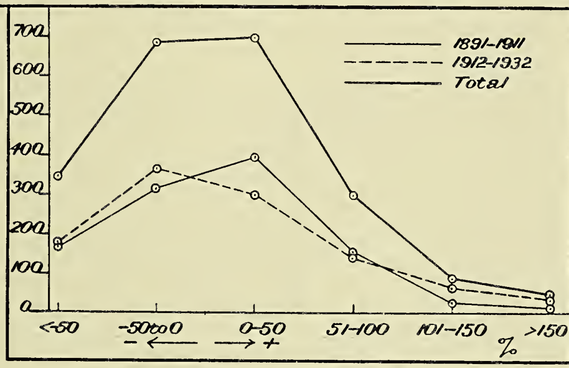

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Text-fig. 10.—Frequencies of volume groups recorded at Albury. Groups are in acre-feet × 100,000.

Text-fig. 11.—Frequency of occurrence of percentage departures from monthly rainfall medians at each station, for the months May-October. Omissions are noted under Table 7.

It seems reasonable to conclude that, in the extra-Jingellic catchment above Albury, no great secular volume changes are disclosed, although trends may be steeper than those actually determined for Tallangatta and Kiewa. At the most, variations due to altered conditions on the catchments are much less than those above Jingellic, although it is probable that the proportions of forest, grassland and cultivation are not dissimilar in the two areas, and the Victorian highlands at the head of Mitta River appear to have suffered more fire damage than those of New South Wales (W. J. Lakeland's unpublished report to the State Rivers and Water Supply Commission, Victoria). A legitimate conclusion appears to be that, for the whole of the Murray catchment above Albury, any effect of partial deforestation on stream flow is quite overshadowed by the operation of other factors (compare Central Board of Irrigation, 1931). The cause of stream changes must therefore be sought in other factors, such as climatic oscillations.

b. The Factor of Rainfall.

The amount of material available for climatic study is limited. There are no rainfall stations on the mountainous part of the Murray catchment, and the nearest one existing under rather similar conditions (at Charlotte's Pass, south-west of Kosciusko station) was established in 1930: up to the present, its figures are about one-third greater than corresponding readings at Kiandra and Batlow. Another disability is the lack of any temperature records for all stations except Kosciusko and Kiandra, so the consideration of rainfall variations is necessarily confined to the cool, moist winter, corresponding to the season of maximum river flow.

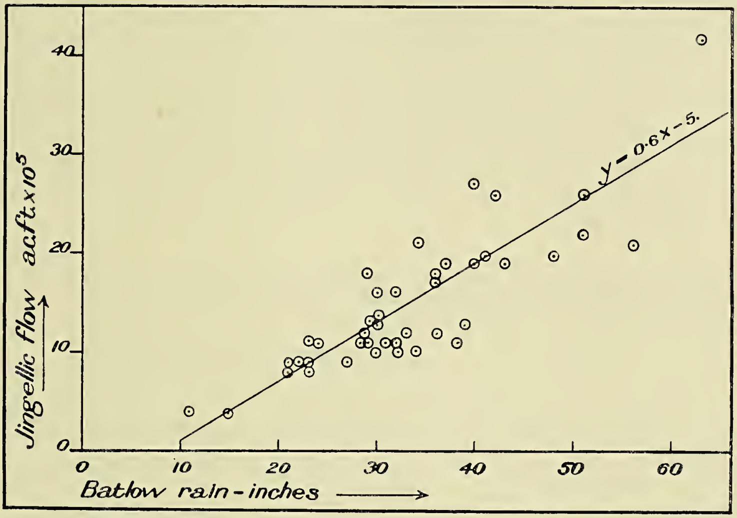
For purposes of comparison, the percentage deviation of each monthly rainfall reading from the corresponding monthly median has been taken, and the individual departures collected into groups in multiples of 50% departure for

TABLE 7.—*Exceptional Departures from Rainfall Medians.*

Departure 50–100% Below.	1887–1909.					1910–1932.					Total 1887–1909.	Total 1910–1932.
	" A."	" B."	Bat-low.	Kian-dra.	Adam.	" A."	" B."	Bat-low.	Kian-dra.	Adam.		
May	9	9	6	2	5	9	10	3	2	4	31	28
June	4	1	1	3	0	11	14	5	4	3	9	37
July	2	13	6	4	6	8	10	3	4	2	31	27
August ..	9	9	5	5	5	8	8	2	2	2	33	22
September ..	7	11	5	1	5	6	10	1	3	2	29	22
October ..	11	15	4	2	5	10	17	5	5	5	37	42
Departure > 50% Above.												
May	9	9	3	2	5	13	17	6	8	9	28	53
June	7	14	4	4	9	8	14	5	4	3	38	34
July	11	13	6	9	4	8	16	5	6	7	43	42
August ..	5	9	1	5	1	9	19	5	1	2	21	38
September ..	9	7	5	3	7	7	18	6	4	6	31	41
October ..	10	10	4	2	9	9	11	3	5	4	35	32
Departure > 100% Above.												
May	4	4	1	—	2	4	10	4	4	7	11	29
June	—	2	—	1	2	3	6	3	1	1	5	14
July	3	2	1	2	1	4	4	4	4	4	9	20
August ..	—	2	—	—	—	2	2	—	—	1	2	5
September ..	1	—	—	—	4	3	3	1	1	2	5	10
October ..	4	2	1	1	3	5	5	2	1	2	11	15

" A " represents the combined total of Holbrook and Albury, and " B " the combined total of Jingellic, Tumbarumba and Tooma, each station being estimated separately. The numbers of monthly totals missing are : Jingellic, 31 ; Tooma, 9 ; Adaminaby, 6. These constitute 2% of the total available, and are equally divided between the two halves. Major anomalies might be : 3 less than −50%, 4 more than 50% for the first half ; 4 less than −50%, 2 more than 50% for the second.

each of the six months of the moist season. The 46-year record available has been halved, and the frequencies of each occurrence expressed by a graph for the whole period, and for the moieties (Text-fig. 11). In this, the first half shows a greater number of positive anomalies and a lesser number of negative than the second, but the position is reversed when extreme deviations are considered: these latter are of the greatest importance, as their multiple occurrences in individual winters are associated with abnormally low or high flows. Thus in the dry winter of 1902, 26 monthly totals out of 48 were less than 50% of their respective medians, while the humid winter of 1917 showed 37 monthly totals with a positive anomaly in excess of 50%. The distribution of these extremes according to various stations and groups of stations is shown by Table 7.



Text-fig. 12.—River flow at Jingellic for the months June-November plotted against Batlow rain for the months May-October in each corresponding year from 1891 to 1932.

Taking the variation groups month by month, it is seen that the second half of the period has more June records below −50% than the first, but that high positive departures have shown a consistent increase over the whole moist season. This applies particularly to the Murray side, with May, June and July benefiting most. The significance of the grouping of the extremes varies from place to place. Batlow is the key station to the highlands, because its general situation and aspect are like those of the high Murray plateau: in both cases, deep valleys radiate from the plateau mass, especially to the west and south-west, and appear to direct the prevailing winter winds blowing from low country, thus giving high rainfall on each plateau. Batlow shows a decreasing tendency in the number of very dry months, and there has been a striking increase in the number of months of excessive rainfall, mostly in the first half of winter. This gives an expectation of rising stream flows, and a similar condition may well be true of the neighbouring Murray highlands, because river flow at Jingellic plotted against rainfall at Batlow gives a series of points which lie approximately on a straight line (Text-fig. 12). Kiandra shows these rainfall changes in a lesser degree, with an increase in the number of dry months, but it is away from the highland edges.

In the lower country on the Murray side, there has been a tendency towards more extreme conditions, but it is doubtful whether an increase in the number of dry months has much effect on stream volumes, because intense or prolonged rain appears to be necessary for any considerable run-off from the deep soils of the gentler slope and plain lands. On the other hand, months of exceptional rainfall contribute much water to the streams, as a large area of catchment is involved, and precipitation is usually widespread. The increase of rainy months is greater in the low plateau and valley country represented by Jingellic, Tooma and Tumbarumba than in the plains of Holbrook and Albury, and as the former section is the more steep and rocky, the increased run-off towards more recent times may be correspondingly high.

Turning now to the upper Snowy, an increased number of months of heavy rainfall at Kiandra and Adaminaby may indicate an increased winter stream flow since the beginning of the record. The position is obscure, because stream gaugings at Jindabyne only date from 1903, and appear to have been controlled by the heavy rainfall country on the eastern side of the Main Divide between Kosciusko and the head of the Tooma River. In that period, the upper Snowy had a more regular flow than the Murray at Jingellic, thus reflecting the rainfall conditions at Kosciusko rather than the less constant precipitation elsewhere (Table 8, Text-figs. 1, 2).

TABLE 8.—*Number of Departures from Medians of June-November Flows, 1903–1932, and Correlation Coefficients for Kosciusko and Kiandra Rainfall (May–October) with Jindabyne Flow (June–December).*

	Percentage Departure from Median.					
	<-50	-50 to 0	0–50	51–100	101–150	>150
Murray at Jingellic	1	14	5	7	2	1
Snowy at Jindabyne	3	12	13	1	1	—

Correlation coefficient (r) = 0·67, probable error = 0·08 for Kosciusko rain and Jindabyne flow, 1912–1932. r = 0·54, probable error = 0·1 for Kiandra rain and Jindabyne flow, 1903–1932.

The extremes of precipitation thus appear to favour increased flood volumes on the Murray in the latter half of the gauging period, and the question arises—are these rainfall variations enough to account for the stream fluctuations observed at Jingellic and Jindabyne? A comparison of departures from rainfall and flow medians for the various periods involved shows that there is a close relationship between the respective departure groups, which suggests that stream and rainfall variations are closely allied (Table 9).

In addition, there is a functional relationship between rainfall and stream volumes for the winter season. The flow at Jingellic is approximately related to Batlow rainfall by the equation—

Flow (acre-feet × 100,000) = 0·6 Rainfall (inches) − 5 (see also Text-fig. 12), and these two variables show a correlation coefficient of 0·86, with a probable error of 0·03. This cannot be regarded as an isolated result, because Tumbarumba, which is actually on the Murray catchment, has a correlation coefficient of 0·83 with the same flow, with a probable error of 0·03. As there is a close corres-

TABLE 9.—*Occurrence of Median Departures of Rainfall and River Flow in Percentage Groups.*

	< −50	−50 to 0	0–50	51–100	101–150	> 150
Period 1891–1932.						
River at Jingellic—						
A	1	11	7	1	1	—
B	1	8	7	3	1	1
Rainfall at Batlow—						
A	1	11	9	—	—	—
B	1	8	8	4	—	—
Period 1903–1932.						
River at Jingellic—						
C	1	7	2	3	1	1
D	—	6	4	4	1	—
Rainfall at Batlow—						
C	1	6	6	2	—	—
D	—	7	6	2	—	—
River at Jindabyne—						
C	2	4	7	1	1	—
D	1	8	6	—	—	—
Rainfall at Kiandra—						
C	1	4	9	1	—	—
D	—	10	4	1	—	—

"A" =1891–1911; "B" =1912–1932; "C" =1903–1917; "D" =1918–1932.

pondence between the median departures of Tumbarumba and those of Jingellic and Tooma rainfall stations, there is no doubt that the latter would give coefficients of a similar order if their records were not slightly imperfect. In other words, stream flow in the upper Murray bears a very close relationship to proximal rainfall, by which it is directly controlled.

Thus it has been shown that the cyclical and secular changes of the upper Murray and, by inference, the Snowy also, have been due to changes in the rainfall regime. The number of exceptionally wet months has shown a tendency to increase, and seasons of the greatest humidity correspond with maximum stream flow, with a linear relationship between precipitation and run-off for the winter season at all times. For the upper Snowy, recent years have seen a slight downward trend in exceptional rainfall and in flood volumes, but the movement towards more extreme conditions of humidity or dryness on the Murray side has given the observed fluctuations of run-off, with the factor of deforestation filling a minor role.

Conclusions.

1. Rainfall and stream regimes for the upper Murray and Snowy Rivers are similar, with a simple maximum in winter and a minimum in late summer in each case. Maximum stream flow is delayed three to four months by the accumulation of snow in the highlands, and moistening of the catchment in the lowlands.

2. The incidence of the annual flood does not show any appreciable alteration over the period of record, but the flow intensity for the six-months flood period has been increasing on the upper Murray, and decreasing on the Snowy.

3. The flow of the upper Murray shows minor cyclical variations with an average period of 12 or 13 years, and a major cycle with a period of 30 years or more.

4. The secular trend of the annual and flood volumes of the Murray is towards increases of the order of 0·5% per annum and that of low water flow is towards a slight increase. The position is reversed in detail on the upper Snowy.

5. Partial deforestation is shown to be only a slight factor in promoting volume changes.

6. Flood volumes show a high correlation with immediate rainfall, and there is an approximately linear relationship between the two. Cyclical and secular variations in flow are due to changes in the rainfall regime, which involve alterations in the amount and concentration of precipitation within the year.

7. From this, it will be seen that the upper Murray streams have become much more effective instruments of erosion during the period of the records, thus accounting mainly for lateral enlargement of channels, the gullying and removal of alluvial deposits, and the cutting of new levels in old stream terraces.

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